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THEORIES REGARDING THE SUN'S CORONA.

Probably most of our readers know that during a total solar eclipse, when the moon for a few moments interposes herself and replaces the dazzling disk of the sun by an inky blot upon the heavens, then, surrounding it appears the "corona," the loveliest and most impressive of all celestial objects; a wonderful glory of silvery light and streaming radiance, revealed to our admiration for an instant, and then immediately withdrawn; accessible to observation and study only for a few minutes in a century. It is no mere structureless luminosity of fog or haze, but is built up of various elements. There are in it brilliant hair-like filaments closely and curiously intertwined; long, bright radiating streamers like comets' tails, and forms like the petals of some luminous flower; all floating in a filmy nebulosity, which here and there is scored by straight, dark rifts cutting clear down through everything to the very edge of the moon, like shadows cast by a gas-light in a dusty air, or like the dark rays one often sees in a summer afternoon reaching outward from the sun before a shower. For the most part, the coronal forms are rather indefinite and uncertainly outlined, confused in dazzling brightness at the base, and fading out insensibly, at a distance that depends much on the clearness of the air and the keenness of the observer's eye. At least, this is true of most of the longer streamers, for often there is a rather surprising degree of sharpness in some of the lower outlines, so that the corona is sometimes described as nearly square, or a five or six rayed star, or like a head with parted hair, according to occasion—never twice alike exactly.

It is obvious that if the corona is really at the sun, it must be of enormous dimensions, extending many hundreds of thousands of miles, and even millions, from the central globe; an object of cosmical importance, to be ranked with nebulæ and comets. If, on the other hand, it can be shown to be due to the lunar atmosphere, and still more if it should turn out to belong to the earth's atmosphere, or, in other words, to be a purely optical phenomenon, then, however beautiful and impressive it may be, it drops to a lower rank, and takes its place with rainbows and halos, and sunset glows. At the outset, the writer may as well affirm his complete conviction that the corona is mainly solar, to be thought of and respected as such, but that purely atmospheric and optical effects contribute more or less to the phenomenon as we see it. At the same time, there are high authorities in solar physics who would dissent from the "mainly solar," and would ascribe a much greater relative importance to the atmospheric and optical elements.

No one at present seems to credit the moon with much influence in the matter, except as a mere screen or shadow-casting body; there is no lunar atmosphere of such extent and character as to account for the corona. At least, this is the almost universal belief of astronomers; and yet it is perhaps not quite impossible that there may really be some exceedingly rare gaseous envelope around our satellite, not dense enough to be perceived at any other time, though still sufficient to become visible under the circumstances of an eclipse. But even if this should turn out to be the case, it may be considered certain that the lunar element of the corona is relatively unimportant.

The explanation that immediately suggests itself to one looking at the matter superficially is undoubtedly that which would refer the corona to the action of the earth's atmosphere. We are so used to seeing illumination around the edge of any object that has a brilliant light behind it, that it is most natural to think of the corona as caused in the same way. Whenever a beam of sunlight is transmitted through air, a portion of the light is diffused into the surrounding space, so that to an eye situated a little one side the air in the path of the beam is intensely luminous. There are curious questions whether this diffusion is due to the air itself, or to minute particles of foreign matter in the air, since the clearer the air the less the illumination; but the diffusion always takes place to a greater or less extent. But when we come to consider the circumstances of an eclipse, it is at once evident that the corona cannot be accounted for in this manner. At the middle of a total eclipse the observer is in the center of a great shadow, from fifty to one hundred and fifty miles in diameter, so that the air in the region of the sky near the sun is as much in the dark as he is himself; the sun does not shine upon it at all, and it cannot therefore by any possibility send him any sunlight. But if there is any real solar or lunar corona, then of course the action of the earth's atmosphere would diffuse the light of this corona just as it would true sunlight; and so, though it cannot cause the phenomenon, the air must modify it, rendering the glory more extensive, softening its sharper outlines, and enveloping them in a luminous haze. And since the air between the eye of the observer and the dark disk of the moon is exposed to the coronal light, this atmospheric illumination must extend inward from the edges of the lunar disk, as well as outward. It does so, making the moon to stand out like a globe, instead of looking like a flat disk; and this illumination of the moon's disk is a fair measure of the atmospheric element in the corona, which is thus shown to be comparatively trifling, though real.

In some way the objections to the atmospheric origin of the corona escaped the notice of even eminent astronomers for a while, and the theory was warmly supported until, and even after, spectroscopic observations settled the matter in 1869 and 1870 by showing that the coronal light is not simple reflected sunlight. If it were, its spectrum would contain all the peculiar dark markings (the Fraunhofer lines) that characterize sunlight; while, in fact, the only conspicuous feature of the spectrum is a brilliant green line, due to some unknown gas. Bright lines due to hydrogen are also present, and there are besides certain other bright lines in the violet and ultra-violet portions of the spectrum, which, though they affect the eye only feebly or not at all, are yet more efficient upon the photographic plate than even the green line. A few of the dark Fraunhofer lines have also been seen occasionally upon a faint background, showing that although reflected or diffused sunlight is not the main constituent of the coronal luminosity, it is still present to some extent. It is to be noticed, moreover, that the bright streamers and other similar markings of the corona seem to give principally a smooth, continuous, unlined spectrum, as if they consisted of incandescent particles, solid or liquid, while the bright green line and the hydrogen lines seem to be due rather to the nebulous light that bathes and permeates the whole. This green line, by the way, is often referred to as "the corona-line," and sometimes as "1474," because upon Kirchhoff's map of the solar spectrum, which was in ordinary use in 1869, it occurs at that number on the scale that is printed alongside the spectrum as a means of reference.

The presence of these bright lines in the spectrum of the coronal light demonstrates two things: that the corona is not luminous by the mere reflection and dispersion of ordinary sunlight by mist, or cloud, or anything of that nature; and further, that the light does come, in considerable measure, at least, from luminous gases at the sun. (We assume that every reader knows that bright-line spectra come only from glowing gas.) This demonstration that the corona is really of solar origin, and not a phenomenon of the lunar or terrestrial atmosphere, is borne out and confirmed by photographic evidence. In 1871 three fine series of photographs of the corona were obtained by observers many hundred miles apart. One station was at Bekul, on the western coast of India, another in northern Ceylon, and still a third on the island of Java. It took the moon's shadow nearly half an hour to traverse the line, and of course the atmospheric circumstances were more or less different at each station. But all the photographs agree with curious precision in all the main features, and even in most of the finer details of the corona. In fact, there are no evident discrepancies whatever, such as must have occurred if there was anything local in the appearance. Since 1870 other similar series of eclipse photographs have been obtained (notably in 1878), and they all tell the same story of the solar nature of the corona.

The hypothesis that seems to meet most of the conditions thus far indicated, and until very recently has commanded the almost unanimous assent of astronomers (and probably does so still), is substantially as follows:

It is supposed that the sun is surrounded by an envelope of mingled gases, in which hydrogen and the unknown substance to which the green line is due are specially predominant. In many respects this gaseous envelope is analogous to the atmosphere of the earth, and so it is often spoken of as a solar atmosphere, but always with the implied reservation that the extreme difference between the solar and terrestrial conditions must necessarily impair the analogy in numerous and important particulars. In this "coronal atmosphere," as Janssen has called it, there are filaments and streamers and other forms that are probably not gaseous, but composed of mist and dust; some of them may be of meteoric origin, and some composed of matter ejected from the sun, while others perhaps are due to the condensation of vapors in the "coronal atmosphere," as clouds are formed in the air. As to the straight, dark rifts, they are more difficult to explain than anything else, but perhaps may be compared to the dark channel in the center of a comet's tail behind the nucleus. The relation of the streamers and filaments to the poles of the sun suggests the operation of forces analogous to those that produce the aurora borealis in our own upper air. At one time, indeed, when the bright line of the corona spectrum was first discovered, the line was supposed to be identical with one of the lines in the spectrum of the aurora; and an attempt (for which the writer was largely responsible) was made to identify the two phenomena, both in respect to the materials concerned and the nature of the forces that produce the characteristic forms. But it did not require any long period of observation to show that the imagined identity of spectra was a mistake; the gaseous elements of the aurora and of the corona are certainly not the same; and while no evidence has been brought to show that magnetic forces on the sun may not be influential in forming and arranging the coronal streamers, just as the earth's magnetism unquestionably does give shape and arrangement to our auroral beams, yet it must be admitted that no progress has been made in establishing the analogy.

If this theory — that the corona is really a solar envelope — is true, then evidently it is an affair of stupendous dimensions. The average width of the luminous ring is at least 15′ on all ordinary occasions, and this implies an average elevation of more than 400,000 miles above the solar photosphere. But many of the streamers extend four or five times as far; and during the eclipse of 1878 some of them were traced, in the clear air of Colorado, to a distance of fully 6°, or more than 9,000,000 miles. If the sun is always really surrounded by such a magnificent nebula, may we not hope to reach the vision of it at some other time than during the few brief moments of eclipse, and in some way to map out its outlines and watch its changes from day to day? The spectroscopic method, which succeeds with the brilliant, cloud-like flames of hydrogen that lie on and close above the solar surface, breaks down with the corona. The spectroscope does indeed, any day, without much trouble, show the bright 1474 line at the edge of the solar disk; but only at the edge, never at any height. Though we can study at our leisure, and with delightful satisfaction, the forms and behavior of the hydrogen prominences, not a glimpse can be obtained of the more delicate, but not less beautiful, texture that lies at the base of the corona, nor of the grander features of the fainter outlying nebulosity.

But it will be remembered that spectroscopic observations at the time of an eclipse have shown that the coronal halo is rich in rays that belong to the ultra-violet. This fact suggested to Dr. Huggins the idea that it might be possible to render visible by photography the coronal forms that do not reach the eye. By the use of a reflecting telescope, with arrangements and appliances that we cannot here describe, he has attained what looks like a success, although it is not so evident and decided as to warrant very positive assertion. Screening off the image of the sun itself from the photographic plate, and taking all possible precautions to prevent the irregular reflection and scattering of light, he obtains, around the circle where the sun's image would be if not screened off, a ghostly phantasm of faint outlines that certainly most closely resemble and simulate what is conspicuous at an eclipse. The shadings are so faint and so indefinite that one naturally fears the effect of his imagination in their interpretation; but nearly all who have seen them agree as to their reality and nature. The plates, moreover, seem to prove that some of the coronal features are quite persistent, lasting for months, and coming round regularly into the same aspect at each solar rotation.

The past year has been so unfavorable for this sort of work, on account of the strange haze that has filled the air, that little, if any, new advance has been made in the investigation. An observer, with suitable apparatus, was sent to the Riffelberg, in Switzerland, last summer, in hopes that the mountain air would prove more transparent and less reflecting than that of the lower regions, thus giving a darker background for the shadowy forms. But, as has been intimated, the newest plates, so far as yet heard from, excel those made by Dr. Huggins two years ago only very slightly, if at all. It is still quite possible to accept them as actual, though feeble, portraits of a real solar nebula, or to reject them as showing to an unprejudiced eye nothing more than such slight inequalities of light and shade as always appear upon a photographic plate when subjected to a prolonged and forced development. Until something more conclusive is obtained, it is likely that opinions will continue to differ in regard to them.

But there are serious difficulties in the way of accepting the idea of a solar atmosphere and a solar nebula as the true explanation of the corona, and there are phenomena that seem to point in a different direction.

The principal objection to the nebula-theory of the corona, if we may call it so, lies in the undeniable difficulty of supposing so deep an atmosphere to surround the sun, consistently with the known intensity of solar gravity, and the ascertained fact that in several cases comets have rushed through the coronal regions with a velocity of from one hundred to three hundred miles a second, and yet have experienced no sensible retardation of their motion; their orbits have shown no change. Granting that the solar atmosphere is governed by the same laws as the terrestrial, it is easy to show that if at the elevation of one hundred thousand miles its density were one-millionth that of the air at the earth's surface, then at the sun's surface it must be many million times denser than lead. The objection, however, is less formidable than at first it looks; because, to begin with, it is not certain, or even likely, that at solar temperatures the same laws of gaseous compression hold as at terrestrial temperature; and besides, the phenomena of comets' tails render it almost indisputable that the sun somehow exerts upon certain forms of matter a powerful repulsive force, which opposes and may neutralize or even overpower gravitation. We have therefore no right to assume that the downward increase of density in the solar atmosphere follows any such rule as holds good upon the earth. And as regards the resistance to comets' motions, it is a gratuitous assumption that the density of the coronal atmosphere is anything like one-millionth that of the air at the earth's surface. The phenomena of Crookes's tubes show that a gas of this low density, even in quantities of only a few cubic inches, can produce light of extreme intensity. It is obvious, therefore, that all the luminous phenomena of the corona, considering the enormous depth of every line of sight drawn through it, could be accounted for by an atmosphere of a density millions of times below that in any vacuum tube ever constructed. One molecule to each cubic inch would probably answer every purpose, so far as the optical phenomena are concerned, while according to the estimates of Professor Johnston Stoney, with which other physicists are in substantial agreement, the number of molecules in each cubic inch of atmospheric air at the sea-level is about twenty thousand millions of millions of millions (20,000,000000,000000,000000). It may be added, that whatever may be the theoretical difficulties in the way of supposing the solar atmosphere to extend to an elevation of one hundred thousand miles, yet the phenomena of solar prominences, and the forms and motions of the hydrogen at their summits, show the actual presence of a surrounding medium (invisible in the spectroscope, of course) comparable in density with the visible hydrogen itself. Other objections, and somewhat serious ones, are drawn from the peculiar polarization of the light in different parts of the corona, which is thought by many to be inconsistent with the nebula-theory. Still another objection, the last we shall mention, lies in the fact that the appearance of the corona is that of something flat. It is very difficult to imagine any arrangement of streamers upon a globe which would look like what we actually see, and the dark straight rifts are especially awkward to explain.

These difficulties, and a few others, which we have not space to discuss here, have led Professor Hastings of New Haven to propose a new theory of the corona, which reduces it to a mere diffraction phenomenon, an optical effect produced by the passage of light from the edges of the solar disk near to the edge of the moon. It is not reflection nor refraction; it implies no action of the terrestrial or lunar atmosphere; but it belongs to the same class of optical effects as the so-called "Grimaldi fringes" at the edge of a shadow, the colors of a soap-bubble, and the iridescence of mother-of-pearl, all of which are due to what is known as the interference of light, *i. e.*, to the combination of overlying and opposing waves under certain peculiar conditions. The idea that the corona might be due to diffraction is not new, but previous mathematical investigations of the matter had shown that, assuming the usual equations of light, the explanation breaks down; no considerable quantity of light could be bent into the moon's shadow. By assuming, however, what is very probably true (for reasons that we cannot here discuss), that at different moments the phases of the light-waves change, in such a way that they no longer form a continuous periodic series, Professor Hastings makes the equations present a different aspect, and it appears quite probable that considerable luminous disturbance might be propagated inside the moon's shadow, so as to give to an observer the impression of a bright fringe around the moon. Any irregularities in the edge of the moon, or in the brightness of different parts of the edge of the sun, would then give rise to straight radial streaks, bright or dark as the case might be, though they could hardly account for the curved forms that are still more common. If this theory is true, the corona ought to be much wider on the side where the edge of the sun is least deeply covered. Professor Hastings proposed this as a crucial test of his theory, and during the eclipse of May, 1883, in the South Pacific, he verified his idea by observations with an ingenious apparatus devised and constructed by himself expressly for the purpose. When the eclipse first became total, the 1474 line was visible on the eastern side of the sun (just covered) to a distance of 10′ or 12′, while on the western edge the extent was barely 3′ or 4′. Just before the close of totality, the conditions were reversed. The only different explanation for this change yet proposed attributes it simply to diffusion of light by our air. The lower part of the corona is so much brighter than the upper, that it scatters light much more widely. Professor Hastings gives strong, if not absolutely conclusive, reasons for rejecting this explanation; and if we renounce it, it will be difficult to avoid admitting the substantial correctness of his theory. One who wishes to understand his ideas fully will find it best to consult the original report, which is just published in the second volume of the "Transactions of the National Academy of Sciences."

To the writer it does not seem that the new theory excludes the old. It may be true that diffraction diverts light coming from points very near the limb of the sun out of its straight course, and causes it to enter the lunar shadow; but this does not negative the idea of a solar atmosphere of considerable extent. The objections urged against the existence of such a nebulous solar envelope, though certainly involving serious difficulties and demanding consideration, do not appear conclusive. Of course, if the corona photographs of Dr. Huggins are accepted, and if they should hereafter be confirmed by new ones of greater clearness, that would close the discussion.

The December number of "The Observatory," which has come to hand since the above was put in type, contains an important letter from Mr. C. Ray Woods, the observer who was sent to the Riffelberg last summer by the Royal Society. His earlier results, as already mentioned, were not much in advance of those previously obtained in England; but later, after a little experience, he seems to have overcome all the most serious difficulties, to have gained the full advantage of his superior atmospheric conditions, and so to have reached unqualified success. We have not space to quote his detailed account of apparatus and methods, and his explanation of the photographic and other principles involved, but only to give his conclusions. He says:

> "As would be expected, the results are better than had been obtained in England, in spite of the red haze which has always been present round the sun, and which visitors to Switzerland have commented on in several of the scientific journals recently. Results on the same day are almost, if not quite, alike, both with the disk and without. The corona varies more or less from day to day. The clearer the day, the better the results. The series extends over a period of two months, one month's results being free from effects that require elimination."

C. A. YOUNG.